

FAME Mechanisms

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FAME Mechanisms Systems



- **Launch Vehicle-Flight Vehicle Separation System**
- **Spacecraft-Interstage Separation System**
- **Star Tracker Cover System**
- **Solar Array Arm Assembly Deployment**
- **Trim Mass System**
- **Radiation Trim Tab System**
- **Other Mechanisms**
 - **Solid Rocket Hole Cover (Currently Not Baselined)**
 - **Main Instrument Cover System (Baselined to Be Done by Lockheed-Martin)**



Launch Vehicle - Flight Vehicle Separation System (1 of 9)

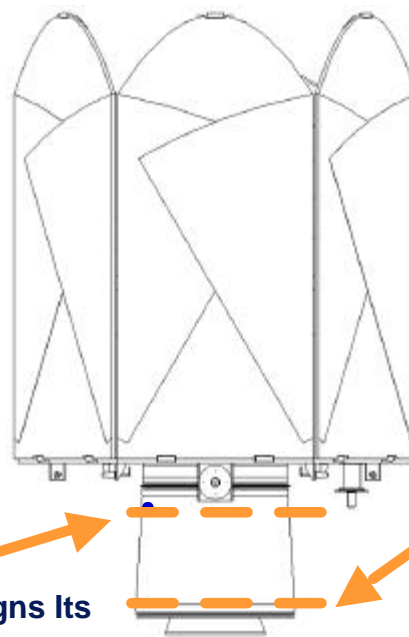


Top Level Requirements (MRD rqrmts in Red)

0. The LV shall provide a Highly Reliable LV-FV Separation System
1. Structurally Hold the Spacecraft to the Launch Vehicle during Launch
2. Provide a Highly Reliable Separation of the FV from the LV
3. Survive and Operate in All Ground and Launch Environments
4. Accommodate Required LV ICD Constraints
5. Design and Installation Procedure Must Be Compatible With Range and Flight Safety Requirements
6. Minimize Cost and Schedule Within the Constraints of the Mission Requirements

Spacecraft/Launch Vehicle Separation Plane

Here If FAME Designs Its Own Clamp



Here If FAME Uses Delta II PAF Clamp (~20+ Inches Lower So Adds ~40lb So Reduces Weight to Orbit by ~40 lb)



Launch Vehicle - Flight Vehicle Separation System (2 of 9)



- **Derived Requirements**
 - **1. Structurally Hold the Spacecraft to the Launch Vehicle During Launch**
 - **1.1. Survive Launch Loads of 3.2* g's Axial Tension & +/-3 g's Lateral (Loads From Delta II Handbook *Added 3.0 g's in Axial Tension for Pogo - #'s TBR)**
 - **1.2. Assure a Linear Separation Joint and No Gapping**
 - **2. Provide a Highly Reliable Separation of the FV from the LV**
 - **2.1. Provide System and Interface that will Separate Cleanly (No Contact) During Separation With Initial LV Tip-Off Rates of Up to 0.2 deg/s (TBR)**
 - **2.1.1. Surrounding Mechanisms, Structure, and Blankets Must Be Designed to Minimize Any Possibility of Grabbing or Catching**
 - **2.2. Provide at Least 1 ft/sec +/- 5% Delta V Between the Spacecraft and Launch Vehicle at Separation to Assure No Recontact by**
 - **2.3. Use Redundant Firing Circuits for Release Mechanisms**
 - **2.4. Use Redundant Release Devices or Redundant Initiators as Appropriate to Provide the Most Reliable Design**



Launch Vehicle-Flight Vehicle Separation System (3 of 9)



- **Derived Requirements (Continued)**
 - **2.5. Use Only Robust/Reliable Design Techniques for Separation**
 - **2.5.1. Separating Surfaces Must Be of Compatible Materials and have Appropriate Finishes and/or Lubricants**
 - **2.5.1.1. Provide an Electrically Conductive Path Across the Separation Joint**
 - **2.5.2. No Binding Angles <20 deg. Between Separating Surfaces**
 - **2.5.3. The Wire Harness to the Release Mechanisms Must Have Adequate Play for the Moving Components**
 - **3. Survive and Operate in All Ground and Launch Environments**
 - **3.1. Survive and Operate in a Temperature Range of +10C to +30C (TBR)**
 - **3.2. Survive LV Pressure Decay Rate of 0.80 psi/sec max. (TBR) and Operate in Hard Vacuum <10⁻⁵ torr**
 - **3.2. Survive and Operate in a Lab Environment**
 - **3.2.1 Temperatures of 20 +/-5 C, 20-80% Humidity, and 1 Atmosphere**
 - **3.3 Provide Any Necessary MAGE Required for This System**
 - **3.3.1. TBD Provide a Ground Handling Fitting to Hold the Interface Together When the Separation System Is Not Available**



Launch Vehicle-Flight Vehicle Separation System (4 of 9)



- **Derived Requirements (Continued)**
 - **4. Accommodate Required LV ICD Constraints**
 - **4.1. Provide TBD Mating Ring With TBD Bolt Pattern**
 - **4.2. TBD LV Firing Circuit Interfaces/Limitations**
 - **5. Design and Installation Procedure Compatibility With Range and Flight Safety Requirements as Defined in TBD Document**
 - **5.1. Two Fault Tolerant Ordnance/Mechanism Firing Design**
 - **5.1.1. Implement Safe/Arm Plug, Enable Cmd, and Fire Cmd to Fire**
 - **5.2. Restrain All Mechanism Parts After Separation**
 - **5.3. Provide Installation Procedure for Range Safety Review**
 - **5.3.1. Use Non-Flammable Materials and Tools**
 - **5.4. Provide Material Safety Data Sheets for Any Ordnance Used**
 - **6. Minimize Cost and Schedule Within the Constraints of the Mission Requirements**
 - **6.1 If Technically Possible Use the Launch Vehicle Provided Separation System because There Is No Additional Cost to the Program if This System Is Used**



Launch Vehicle-Flight Vehicle Separation System (5 of 9) - (Back-Up)

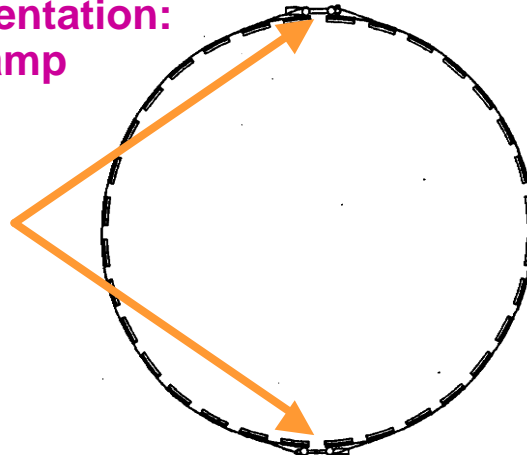


Major Trade: What Type Separation System to Use

	Marman Clamp	Separation Nuts/Joints (4)	Separation Nuts/Joints (8)
Load Path	Excellent	Poor	Fair
Weight	Good	Poor	Poor
Redundancy	Excellent	Good	Good
Required Ordnance	Good (2 - 4)	Fair (8)	Poor (16)

Selected Implementation: Marman Clamp

Separation Devices in
Two Places
(Clamp Will Separate
if Either or Both
Devices Fire)



- Best Load Path (Cylinder to Cylinder)
- Significantly Lighter Than a 4 or 8 Separation Nut/Joint Systems
 - WRT Mechanisms Weight, Structure Weight, and Ordnance System Weight
- Reduces Required Ordnance From 16 Lines to 4 Lines (Maximum)
- Inherently Redundant

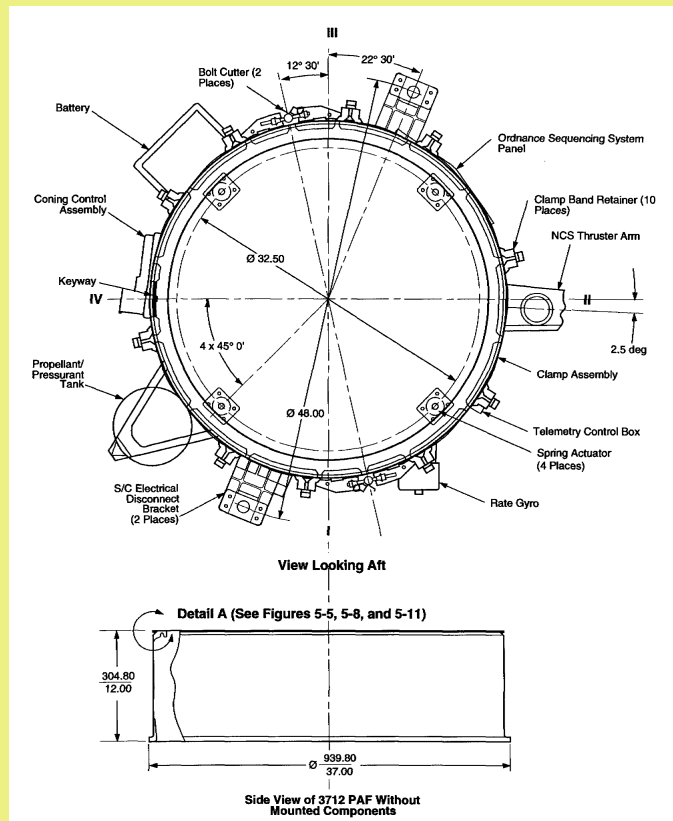


Launch Vehicle-Flight Vehicle Separation System (6 of 9) - (Back-Up)

Major Trade: Use Delta Clamp or Custom FAME Clamp
(1 of 2)



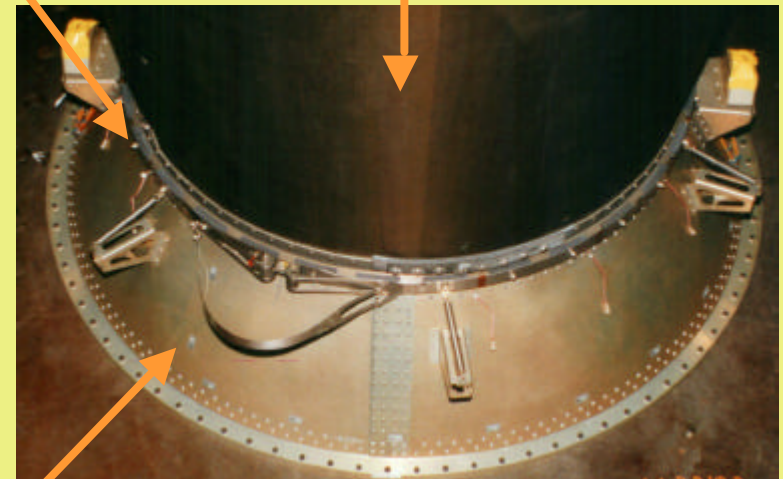
Drwg of Delta's 3712 Payload Adapter Fitting



FAME Would Build the "Top" Ring of
This Marman Clamp System into the
Spacecraft Interstage
Note: The "Bottom" Ring Is an Integral
Part of This PAF Assy

Example of Custom FAME Clamp Configuration

Clamp Interstage to the Spacecraft



(Clementine Marman Clamp Shown)

LV Adapter

FAME Would Build the "Top" Ring of This
Marman Clamp System into the Spacecraft
Interstage and Provide an Adapter With
the "Bottom" Ring and With a Bolt Pattern
Interface to the Launch Vehicle



Launch Vehicle-Flight Vehicle Separation System (7 of 9) - (Back-Up)



**Major Trade: Use Delta Clamp or Custom FAME Clamp
(2 of 2)**

	Delta 3712 PAF Marman Clamp	Custom FAME Marman Clamp
Weight	Fair	Good (Saves ~40 lb)
Cost	Excellent (Comes w/ Delta Cost)	Poor (Est. ~\$500k + TBD Delta PAF Modification costs.)
All Other Design Features and Benefits (Reliability, Functionality, Etc)	Same	Same

- **Specific Implementation Recommendation**
 - **Baseline Delta II PAF 3712 (Type B or C) Marman Clamp**
 - Note: B & C Ring Types Need Further Investigating – However C Is Lighter and Is Currently Preferred
 - Option: If Weight to GEO Becomes Critical Can Gain About 40 lb by Designing a FAME Specific Marman Clamp and Changing the Delta PAF Interface to a Bolt Pattern – Decide by 5 Months Prior to PDR to Avoid Any Schedule Delays



Launch Vehicle-Flight Vehicle Separation System (8 of 9) - (Back-Up)



- **Critical Design Calculations**
 - **At Delta II 3712 Marman Clamp Interface**
 - Line Load N= 295 lb/in
 - Required Preload= 4000 lb (3600 lb Min to 4800 lb Max)
 - Given
 - Loads 3.2* g's Axial Tension, +/- 3 g's Lateral (From Delta II Hdbk *Added 3.0g's)
 - Weight = 2290 lb at 49.1 Inches Above Separation Plane
 - Shoe and Ring Angle = 20 degrees
 - +/-20% Preload Variation (No Gages)
 - **Includes a Program Maturity Factor of 2.0 Applied to the Line Load to Account for Typical Weight and Loads Growth**
 - Use 2.0 Thru SRR, 1.75 at PDR, 1.5 at CDR, 1.1 Post Coupled Loads Analysis and CDR Weight
 - **Results Show Delta II PAF 3712 (Type B or C) Marman Clamp Will Support the FAME Loads With a FS= 5700/4800= 1.2 on Preload**
 - PAF 3712 (B or C) Clamp Maximum Preload Is 5700 lb From Delta II Hdbk



Launch Vehicle-Flight Vehicle Separation System (9 of 9) - (Back-Up)



- **Critical Design Calculations**
 - At FAME Custom Clamp Interface (-12 in From Z=0 Datum)
 - Line Load N= 231 lb/in
 - Required Preload= 3100 lb (2500 lb Min to 3700 lb Max)
 - Given
 - Loads 3.2* g's Axial Tension, +/- 3 g's Lateral (From Delta II Hdbk *Added 3.0g's)
 - Weight = 2290 lb at 30.1 Inches Above the Separation Plane
 - Shoe and Ring Angle= 20 Degrees
 - +/-20% Preload Variation (No Gages)
 - Includes a Program Maturity Factor of 2.0 Applied to the Line Load to Account for Typical Weight and Loads Growth
 - Use 2.0 Thru SRR, 1.75 at PDR, 1.5 at CDR, 1.1 Post Coupled Loads Analysis and CDR Weight
 - Results Show *Clementine* Marman Clamp Design will Probably Support the FAME Loads (*Clementine* Qualified to N=240 lb/in and a Preload of 3600 lb +/- 400lb)
- **Long Lead Items**
 - N/A : Clamp Comes With Delta III
- **Issues**
 - No Foreseen Issues

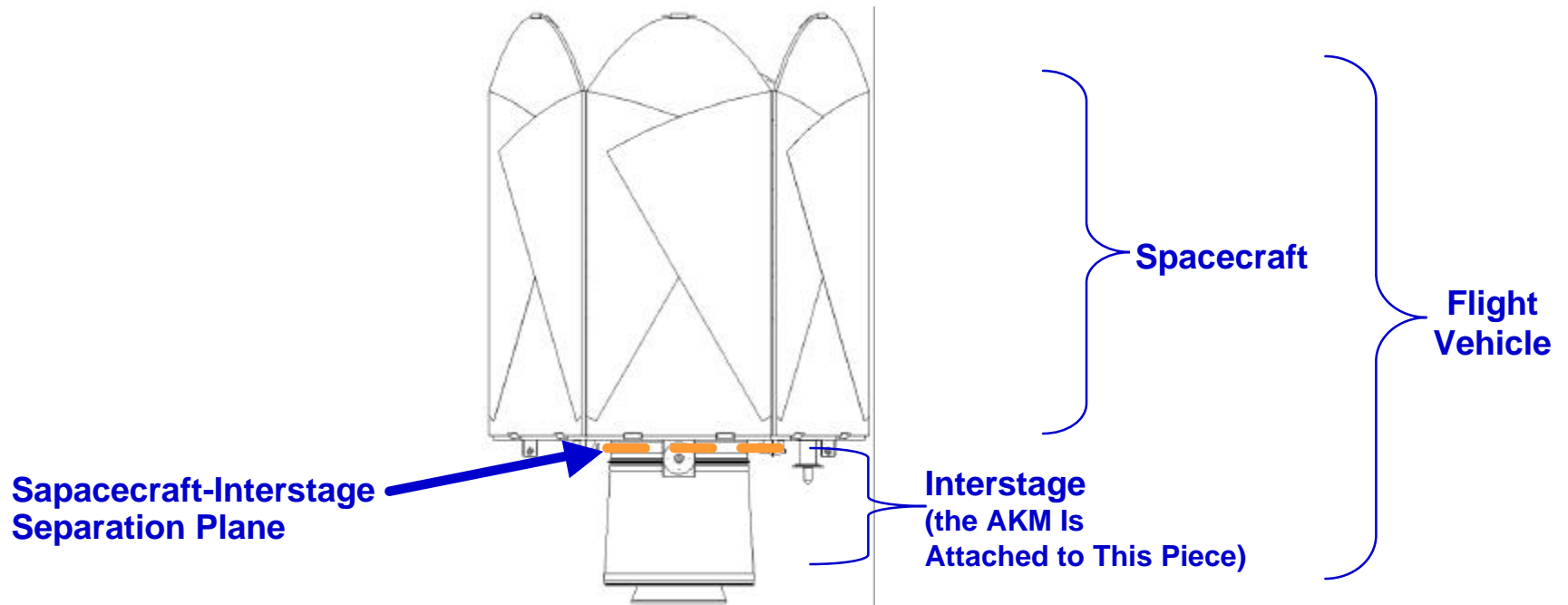


Spacecraft-Interstage Separation System (1 of 7)



Top Level Requirements (MRD rqrmts in Red)

0. **Provide a Highly Reliable Spacecraft-Interstage Separation System**
1. Structurally Hold the Spacecraft to the Interstage During Launch and Orbit Transfer Maneuvers
2. Provided a Highly Reliable Separation of the Spacecraft From the Interstage
3. Survive and Operate in All Ground, Launch, and Orbit Transfer Environments
4. Accommodate Required Spacecraft Structure – i.e. Sun Shield
5. Design and Installation Procedure Must Be Compatible With Range and Flight Safety Requirements
6. Minimize Cost and Schedule With in the Constraints of the Mission Rqrmts





Spacecraft - Interstage Separation System (2 of 7)



- **Derived Requirements**
 - **1. Structurally Hold the Spacecraft to the AKM During Launch and Orbit Transfer Maneuvers**
 - **1.1. Survive Launch Loads of 3.2* g's Axial Tension and +/-3 g's Lateral (TBR Loads From Delta II Handbook *Added 3.0 g's Axial Tension for Pogo) and TBD Circularization Burn Loads**
 - **1.2. Assure a Linear Separation Joint and No Gapping**
 - **1.3. Provide a Marman Clamp Capable of Supporting a Line Load of N=132 lb/in on a 36 inch Diameter**
 - **1.3.1. Use Clamp Shoe Ramp Angles of 20 deg (Optimum for Carrying Loads and Avoiding Separation Issues)**
 - **1.3.2. Sep Bolt Must Support the Required Preload of 2200 lb With a FS>= 2.0**
 - **2. Provided a Highly Reliable Separation of the Spacecraft from the Interstage**
 - **2.1. Provide a System and Interface That Will Separate the Spacecraft From the Interstage Cleanly (No Contact) During Separation With Initial Spacecraft Tip-off Rates of TBD Deg/s Maximum**
 - **2.1.1. Surrounding Mechanisms, Structure, and Blankets Must Be Designed to Minimize Any Possibility of Grabbing or Catching**
 - **2.1.2. Perform Rigorous Fit and Qualification Tests, Environmental Testing IAW NCST-TP-FM001, FAME Test Plan**



Spacecraft-Interstage Separation System (3 of 7)



- **Derived Requirements (Continued)**
 - **2.2. Assure No Recontact by Providing at Least 1 ft/sec +/- 5% Delta V between the Satellite and the Interstage at Separation**
 - **2.3. Use Redundant Firing Circuits for Release Devices**
 - **2.4. Use Redundant Release Devices or Redundant Initiators as Appropriate to Provide the Most Reliable Design**
 - **2.5. Use Only Robust/Reliable Design Techniques for Separation**
 - **2.5.1. Separating Surfaces Must Be of Compatible Materials and have Appropriate Finishes and/or Lubricants**
 - **2.5.1.1. Provide an Electrically Conductive Path Across the Separation Joint**
 - **2.5.2. No Binding Angles <20 deg Between Separating Surfaces**
 - **2.5.3. The Wire Harnesses to the Release Devices Must Have Adequate Play for the Moving Components**
 - **3. Survive and Operate in All Ground, Launch, and Orbit Transfer Environments**
 - **3.1. Survive and Operate in a Temperature Range of -20C to +50C (TBR)**
 - **3.2. Survive LV Pressure Decay Rate 0.8 psi/sec max. and Operate In Hard Vacuum <10⁻⁵ torr**
 - **3.3. Survive and Operate in a Lab Environment**
 - **3.3.1. Temperatures of 20 +/- 5 C, 20-80% Humidity, and 1 Atmosphere**



Spacecraft -Interstage Separation System (4 of 7)



- **Derived Requirements (Continued)**
 - **3.4 Provide Any Necessary MAGE for the System**
 - **3.4.1 Provide a Ground Handling Fitting to Hold the Interface Together When the Separation System Is Not Available (Should Probably Move This Requirement to I&T)**
 - **4. Accommodate Required Spacecraft Structure – ie. Sun Shield**
 - **4.1. Design, Separation, and Particularly Installation Must Accommodate Space Limitations Due to Surrounding Structure**
 - **5. Design and Installation Procedure Must Be Compatible With Range and Flight Safety Requirements**
 - **5.1. Two Fault Tolerant Ordnance/Mechanism Firing Design**
 - **5.1.1. Implement Safe/Arm Plug, Enable Cmd, and Fire Cmd to Fire**
 - **5.2. Restrain All Mechanism Parts After Separation (No Parts Can Be Released Into Space)**
 - **5.3. Provide Installation Procedure for Range Safety Review**
 - **5.3.1. Use Non-Flammable Materials and Tools**
 - **5.4. Provide Material Safety Data Sheets for Any Ordnance Used**
 - **6. Minimize Cost and Schedule With in the Constraints of the Mission Requirements**
 - **6.1. Attempt to Reuse the *Clementine* Marman Clamp Design**
 - **6.1.1. FAME Sep Bolt Must Be Identical in Form and Fit to the *Clementine***



Spacecraft-Interstage Separation System (5 of 7) - (Back-Up)

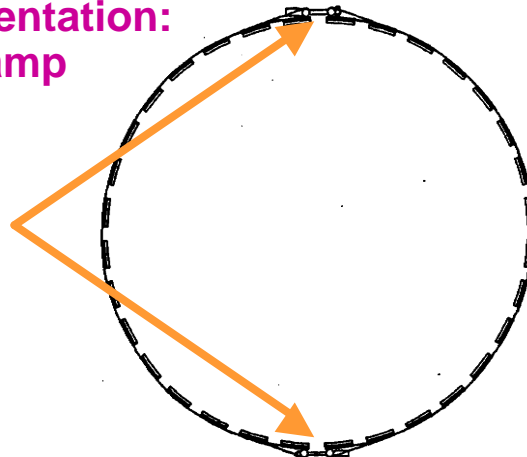


Major Trade: What Type Separation System to Use

	Marman Clamp	Separation Nuts/Joints (4)	Separation Nuts/Joints (8)
Load Path	Excellent	Poor	Fair
Weight	Good	Poor	Poor
Redundancy	Excellent	Good	Good
Required Ordnance	Good (2 - 4)	Fair (8)	Poor (16)

Selected Implementation: Marman Clamp

Separation Devices
in Two Places
(Clamp Will
Separate if Either or
Both Devices Fire)



- Best Load Path (Cylinder to Cylinder)
- Significantly Lighter Than a 4 or 8 Separation Nut/Joint Systems
 - WRT Mechanisms Weight, Structure Weight, and Ordnance System Weight
- Reduces Required Ordnance From 16 Lines to 4 Lines (Maximum)
- Inherently Redundant

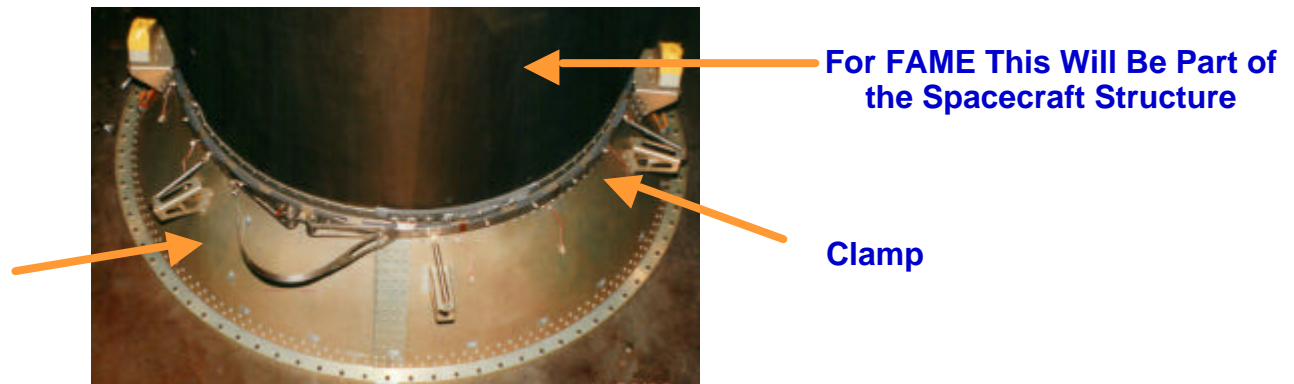


Spacecraft -Interstage Separation System (6 of 7) - (Back-Up)



- Critical Design Calculations
 - At Spacecraft / Solid AKM Separation Plane (Z=0 in)
 - Line Load N= 132 lb/in
 - Required Preload= 1800 lb (1400 lb Min to 2200 lb Max)
 - Given
 - Loads 3.2* g's Axial Tension, +/- 3 g's Lateral (From Delta II Hdbk *Added 3.0g's)
 - Weight = 1240 lb at 34.1 Inches Above Separation Plane
 - Shoe and Ring Angle= 20 Degrees
 - +/-20% Preload Variation (No Gages)
 - Includes a Program Maturity Factor of 2.0 Applied to the Line Load to Account for Typical Weight and Loads Growth
 - Use 2.0 Thru SRR, 1.75 at PDR, 1.5 at CDR, 1.1 Post Coupled Loads Analysis and CDR Weight
 - Results Show the *Clementine* Marman Clamp Design Will Support the FAME Loads (*Clementine* Qualified to N=240 lb/in and a Preload of 3600 lb +/- 400 lb)

For FAME This Will Be an Interstage
Note: the AKM Will Be Attached to This Side



Clementine Marman Clamp Shown



Spacecraft-Interstage Separation System (7 of 7) - (Back-Up)



- Long Lead Items
 - Sep Bolt Hi-Shear SC1005-4D Clamp Separator, Part # 9362693-2
 - Quote Received \$95k - 11 Months Lead Time (8 Months + 3 Months Pre-Award Procurement Work)
 - NRL Does Have Some Sep Bolts in Stock for Early Installation Procedure Development and Testing
 - Power Cartridge PC72-003, Part # 939714-003
 - Quote Received \$45k - 11 Months Lead Time (8 Months + 3 Months Pre-Award Procurement Work)
 - However – PC72-003's Are NSI Equivalents and NRL Has Many NSI's in Stock That I Believe Can Be Used As Substitutes – If This Works Out Then There Would Be No Cost for the Ordnance
 - Note: the Basic Difference Between PC72-003's and NSI's Is the Lack of Some Extreme Temperature Testing Such Ss at Cryo Temperatures
- Issues
 - None



Star Tracker Cover System (1 of 6)



- **Top Level (MRD Requirements in Red)**
 - **0. Provide Multi-Use, Cleanliness Covers to Protect the Star Trackers During Spacecraft Integration and Testing, Field Operations, Launch, and Solid Rocket Motor Burns**
 - **1. Protect Star Trackers From Debris Contamination During Spacecraft I&T, Field Ops, Launch, and During AKM Burns**
 - **2. Assure Highly Reliable Operation**
 - **3. Survive in Ground, Launch, and Space Environments**
 - **Operate in the Ground and Space Environments**
 - **4. Minimize Cost and Schedule Within the Constraints of the Mission Requirements**



Star Tracker Cover System (2 of 6)



- **Derived Requirements**
 - **1. Protect Star Trackers From Debris Contamination During Spacecraft I&T, Field Ops, Launch, and During Solid Rocket Burns**
 - **1.1. Prevent 0.001 in and Greater Diameter Particles and From Passing Through the Seal**
 - **1.2. Multi-Use**
 - **1.2.1. Required Life Cycles of at least 3 (TBR) Open/Close Cycles On-Orbit**
 - **Note: Do Not Need to Cover Camera During Mono-Prop Hydrazine Thruster Burns or to Protect From Sun**
 - **2. Assure Highly Reliable Operation**
 - **2.1. Use Redundant Electrical Actuation Circuits**
 - **2.2. Use High Force/Torque Opening Margins**
 - **2.3 Use Appropriate Materials and Lubricates for Sliding and Separating Parts**
 - **2.3.1 Use Redundant Sliding Surfaces Where Practical**
 - **2.4. Perform Rigorous Qualification and Acceptance Testing, Environmental Testing IAW NCST-TP-FM001, FAME Test Plan**



Star Tracker Cover System (3 of 6)



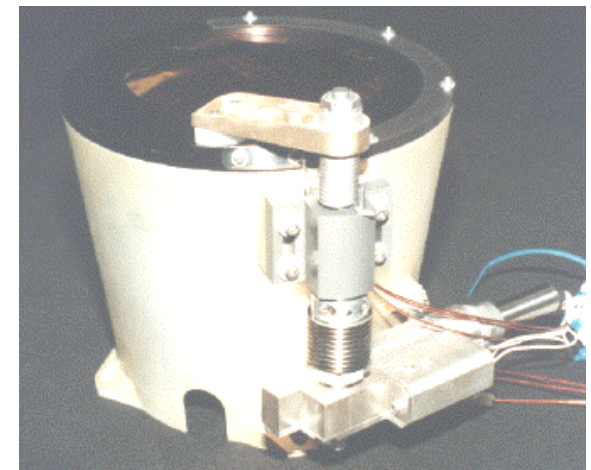
- **Derived Requirements (Continued)**
 - **3. Survive in Ground, Launch, and Space Environments; Operate in the Ground and Space Environments**
 - **3.1. Survive TBD Component Vibration Spec**
 - **3.2. Survive and Operate in a -40 C to +60 C (TBR) Temperature Environment**
 - **3.3. Survive LV Pressure Decay Rate of 0.8 psi/sec Max. and Operate In Hard Vacuum <10⁻⁵ torr**
 - **3.4. Survive and Operate in a Lab Environment**
 - **3.4.1 Temperatures of 20 +/-5 C, 20-80% Humidity, and 1 Atmosphere**
 - **3.5 Provide Any Necessary MAGE Required for This System**
 - **4. Minimize Cost and Schedule Within the Constraints of the Mission Requirements**
 - **4.1. Attempt to Reuse or Modify the *Clemetine* or ICM Star Tracker Cover Designs**



Star Tracker Cover System (4 of 6) - (Back-Up)



- **Design Approach**
 - Anticipate a Paraffin Actuated Cover With a Binary Latch
- **Trade Studies**
 - Actuator Types
 - Seal Geometry
 - Attach Cover to the Baffle or to a Separate Cover Structure
- **Long Lead Components**
 - Actuator - Paraffin Actuators Typically Less Than 6 Months
 - Binary Latch – 6-9 Months
- **Issues**
 - No Technical Issues Anticipated



Clementine Star Tracker Cover
- Paraffin Actuated
- Binary Latch Mechanism to Hold Cover Open

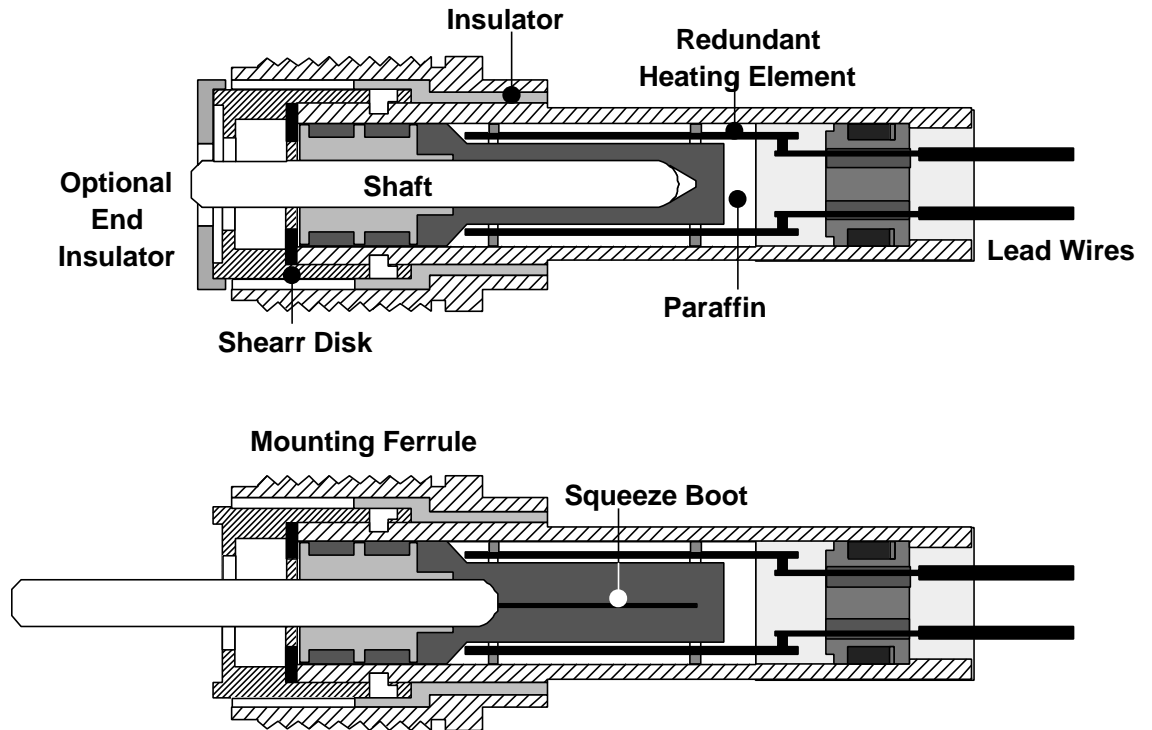


Star Tracker Cover System (5 of 6) - (Back-Up)



- **Actuator Specifications**

- **Low Weight:**
Typically 0.125 lb
- **Power Requirements:**
10 W For 120 sec
- **High Reliability:**
 - One Moving Part
 - Redundant Heaters
- **Robust to Environments**
 - Vibration Qualified to XXX Grms
 - Operates From -40C to +65C
 - Will Not Self Actuate Up to 80C



Paraffin Actuator

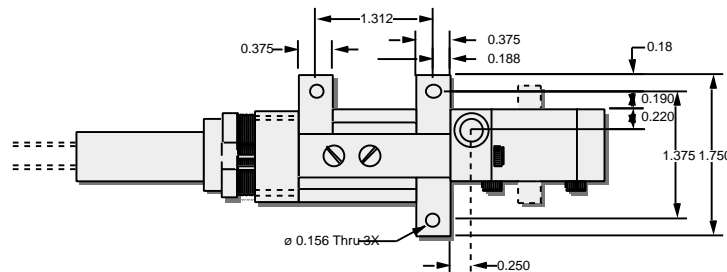


Star Tracker Cover System (6 of 6) - (Back-Up)

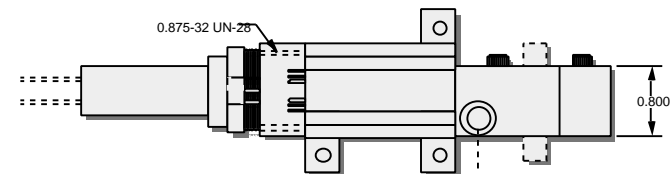


- Starsys RF-1035 Rotary Binary Latch

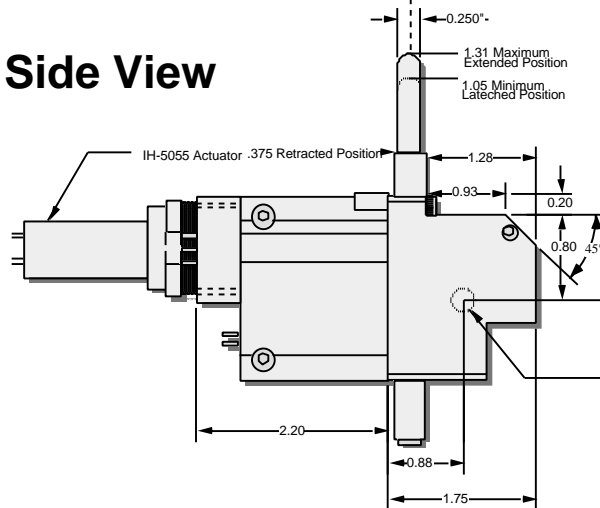
Top View



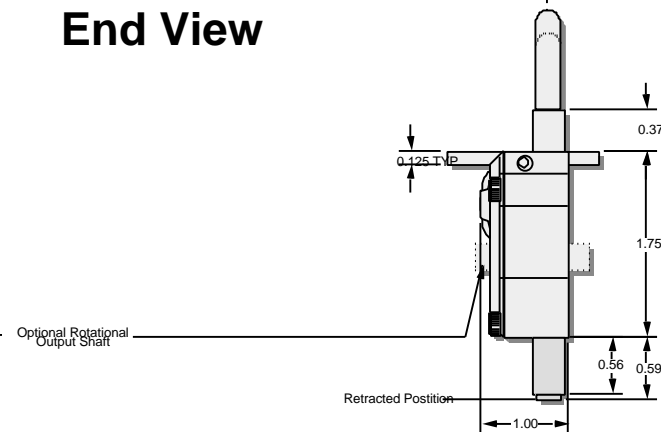
Bottom View



Side View



End View



STC-Rot Bin Latch



Solar Array Arm Assembly Deployment (1 of 9)



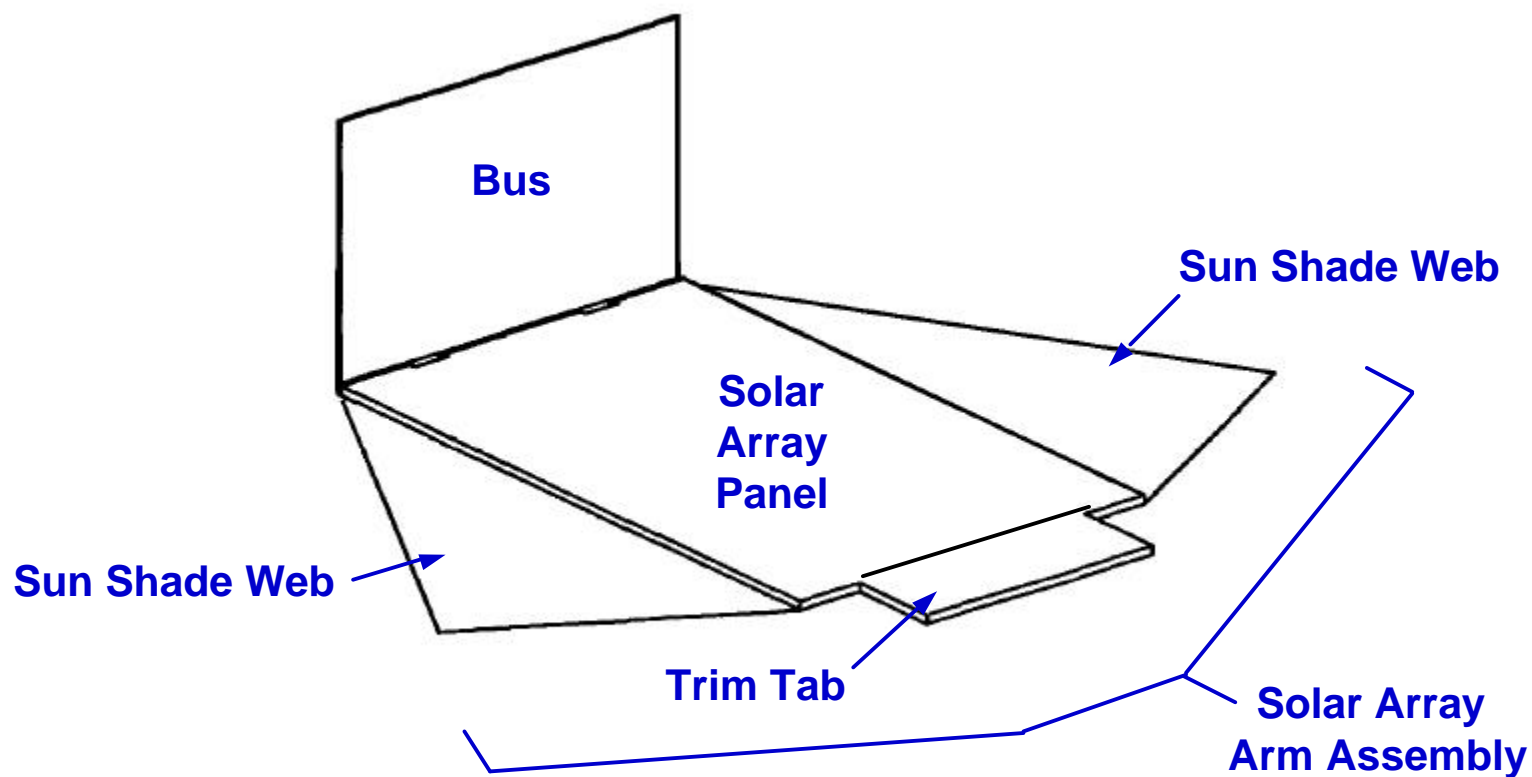
- **Top Level Requirements (MRD Requirements in Red)**
 - **0. Provide a Highly Reliable System for Deploying the Solar Array Arm Assemblies**
 - **1. Deploy Solar Array Arm Assemblies to Provide the Proper Spacecraft Power and to Protect Primary FAME Instrument From the Sun**
 - **2. Provide a Highly Reliable Deployment**
 - **3. Assure Deployed Sun Shade Surface Is Compatible With ACS Radiation Spin and Precession Scheme**
 - **4. Survive in Ground, Launch, and Space Environments; Operate in the Ground and Space Environments**
 - **5. Minimize Cost and Schedule Within the Constraints of the Mission Requirements**
 - **Note: Acronym SSDS = Solar-Array and Sun-Shield Deployment System**



Solar Array Arm Assembly Deployment (2 of 9)



Terminology

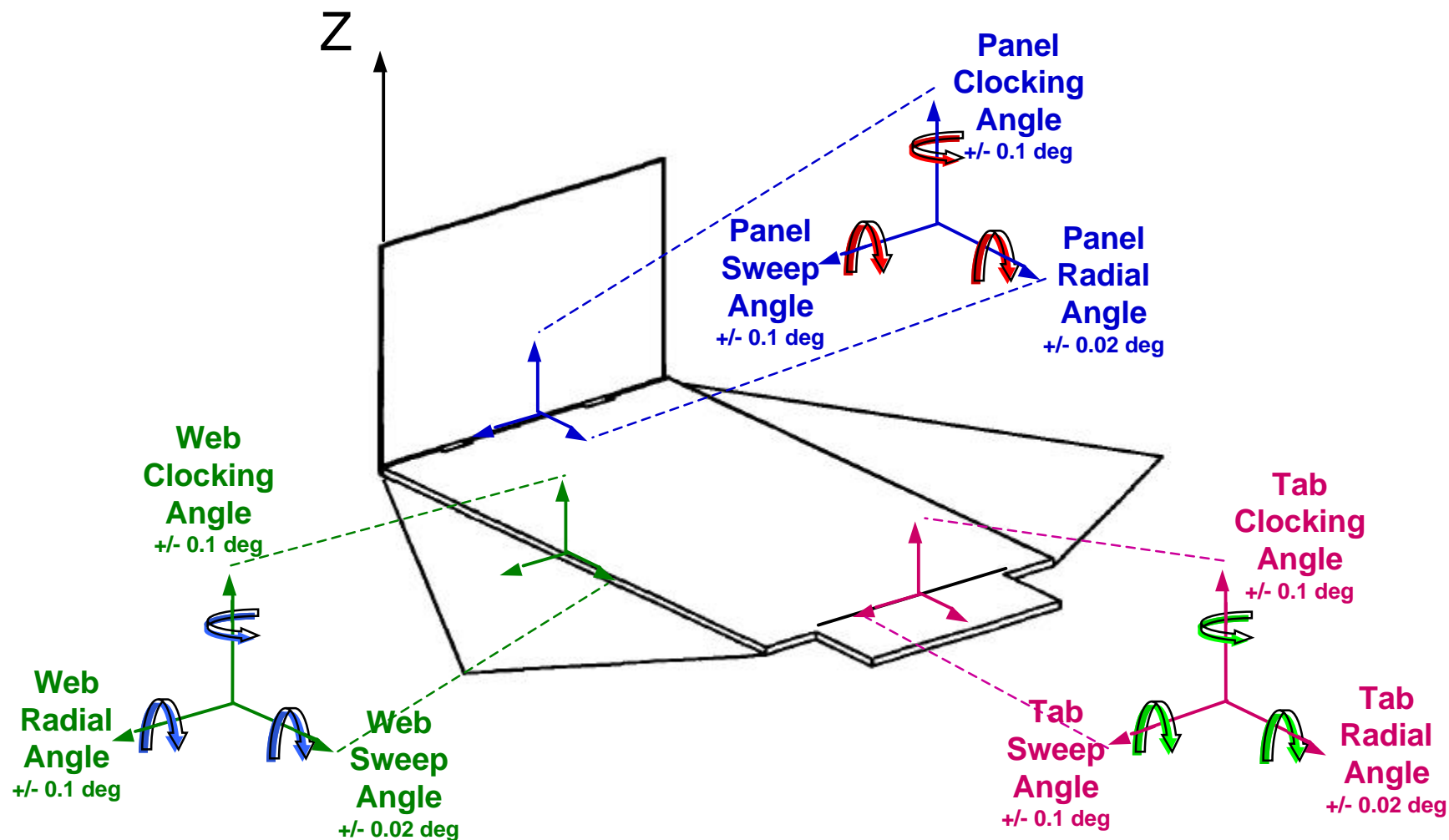




Solar Array Arm Assembly Deployment (3 of 9)



Coordinate Frames





Solar Array Arm Assembly Deployment (4 of 9)



- **Derived Requirements**
 - **1. Deploy Solar Array Arm Assemblies to Provide the Proper Spacecraft Power and to Protect the Primary FAME Instrument From the Sun**
 - **1.1. Deploy the Solar Array Arm Assemblies to 0 Degrees (TBR), Parallel to the X-Y Plane (Note: This Geometry Provides the 50 [45 +/-5] FOV Sun Protection)**
 - **1.2 Minimize Shock As Practical to Reduce Risk of Solar Cell Damage**
 - **2. Provide a Highly Reliable Deployment**
 - **2.1. Use Redundant Electrical Actuation Circuits**
 - **2.2. Use High Force/Torque Deployment Margins**
 - **2.3. Use Appropriate Materials and Lubricates for Sliding and Separating Parts**
 - **2.3.1. Use Redundant Sliding Surface Where Practical**
 - **2.4. Perform Rigorous Qualification and Acceptance Testing, Environmental Testing IAW NCST-TP-FM001, FAME Test Plan**
 - **3. Assure Deployed Sun Shade Surface Is Compatible With ACS Radiation Spin and Precession Scheme**
 - **3.1. Minimum Natural Frequency of 7 Hz (TBR-From 1/10 of 1.56 s Integration Time) (Mech & Strct Requirement)**



Solar Array Arm Assembly Deployment (5 of 9)



- **Derived Requirements (Continued)**
 - **3.2. Deploy the Solar Array Arm Assemblies Flat and Maintain Their Flatness**
 - **3.2.1 Deploy Sweep Angle to ± 0.1 deg. and Maintain Flatness on Each Assembly (Equivalent to 0.153 Inches Over 88 Inches)**
 - **3.2.2 Deploy Radial Angle to ± 0.02 deg. and Maintain Flatness (TBR) on Each Assembly**
 - **3.2.3 Deploy Clocking Angle to ± 0.1 deg**
 - **3.2.4 Deploy and Maintain X,Y,Z-Axis Translation Error to Within ± 0.010 Inches (TBR)**
 - **3.2.5. Minimize Non-Flat Features (Mech and Strct Requirement)**
 - **3.2.5.1. Maximum Height Discontinuity of 0.25 inches (TBR) With TBD Area Across Entire Surface (Mech, Strct, TCS, EPS Rqmt)**
 - **3.2.5.2. Maximize Symmetry of Disturbing Features (Mech, Strct, TCS, EPS Rqmt)**
 - **Note: True ACS Concern - Error Between Opposite Panels**



Solar Array Arm Assembly Deployment (6 of 9)



- **Derived Requirements (Continued)**
 - **4. Survive in Ground, Launch, and Space Environments; Operate in the Ground and Space Environments**
 - **4.1. Survive TBD Component Vibration Spec**
 - **4.2. Survive Panel Temp. Range of -40 to +125 C (TBR) and Operate (Deploy) in +0 to +60 C (TBR) Temperature Environment and TBD Release Device Temps**
 - **4.3. Survive LV Pressure Decay Rate 0.8 psi/sec Max. and Operate In Hard Vacuum <10⁻⁵ torr**
 - **4.4. Survive and Operate in Lab Environment**
 - **4.4.1. Temperatures of 20 +/-5 C, 20-80% Humidity, and 1 Atmosphere**
 - **4.5. Provide any Necessary MAGE for the SSDS System**
 - **4.5.1. Provide Retention Device to Hold the SSDS Stowed Against the Bus When the Release Devices Are Not Available or Are Being Installed**
 - **5. Minimize Cost and Schedule Within the Constraints of the Mission Requirements**
 - **5.1 If Technically Feasible Deploy 6 Separate Solar-Array Arm Assemblies Instead of 1 Integrated Assembly Because the Complexity and Testing Costs are Significantly Reduced**
 - **5.2 If Technically Feasible Deploy the SSDS Via Rotation About Only 1 Primary Hinge Versus 2 or More Because 1 Hinge Significantly Reduces Design and Analysis Effort**

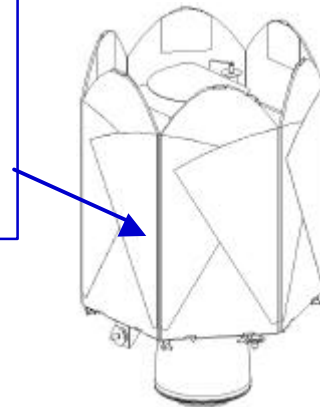


Solar Array Arm Assembly Deployment (7 of 9) - (Back-Up)

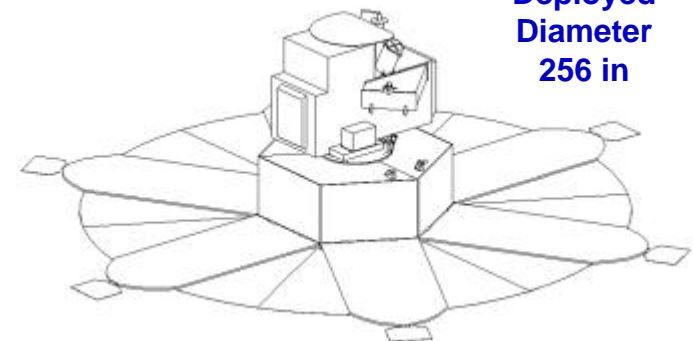


- **Design Approach**
 - Deploy in 6 Arm Assemblies
 - Each Assembly Contains a Honeycomb Center Panel With 2 Sheet Metal or Honeycomb Side Panels
 - A Single Releases Device Each Segment
 - 1 Spring Driven Hinge Deploys and Latches the Center Panel of Each Segment and Spring Driven Hinges Deploy and Latch the side Panels While
- **Trade Studies**
 - One or Two Hinge System (One Hinge Baseline)
 - Release Device
 - Segmented Panel System Verses a “One Piece” System Such a Tensioned Mesh Connecting Each Panel
- **Long Lead Components**
 - Release Devices Take 6–12 Months
- **Issues**
 - Need to Verify the Baseline Design Approach Is Capable of Meeting the ACS Flatness Requirements
 - If Not Then a Much More Complex, “One Piece”, Tensioned Web Type System Will Be Required
 - The Design and Testing Would Both Become Much More Complex

1 Segment
-1 Center Panel
-2 Side Panels
-Released by a
Single Release
Device



Sun Shield Stowed



Deployed
Diameter
256 in

Sun Shield Deployed



Solar Array Arm Assembly Deployment (8 of 9) - (Back-Up)



- Deployment System Trade Study

	Segmented, Honeycomb Panel Based System	“One Piece” Tensioned Web System
Ability to Block Sun	Excellent	Fair
Ability to Meet ACS Flatness Rqmts	Good/Poor (TBD)	Good
Weight	Good	Good
Simultaneous Release	NOT Required	Required
Design Simplicity	Excellent	Fair
Testing Simplicity	Excellent	Poor

- Segmented, Honeycomb Panel Based System Is Baselined Pending Verification That It Can Meet the ACS Flatness Requirements



Solar Array Arm Assembly Deployment (9 of 9) - (Back-Up)



- **Release Device Trade Study**

	Frangibolts	Bolt Cutters	Separation Nuts
Weight	Excellent	Good	Poor
Redundancy	Excellent	Good	Good
Safety	Excellent	Fair	Fair
Power	Poor (90 W For 30 sec)	Good (5 A for 2 ms)	Good (5 A For 2 ms)
Shock	Fair	Good	Fair
Fast-Simultaneous Release	NO	Yes	Yes

- **Frangibolts Are the Baselined Release Device**
 - **Pending Confirmation That Design Will Not Require Simultaneous Release**
 - **A More Detail Trade Study Will Be Done to Consider Some of the Newer Mechanisms, Several of Which Have Lower Shock and Simultaneous Release**



Trim Mass System (1 of 5)



- **Top Level (MRD Requirements Shown in Red)**
 - **0. Provide Trim Mass Mechanisms With the Capability to Adjust the Location of the Center of Mass and to Adjust Selected Inertias Throughout the Life of the Mission (Note: Adjustments Will Not Be Made During Stellar Mapping)**
 - **1. Adjust the CG in the Radial Axis (in the X & Y Axis)**
 - **2. Adjust I_{xz} & I_{yz}**
 - **3. Provide Highly Reliable Operation Throughout the Mission's Life**
 - **4. Minimize Operational Impact on Mission**
 - **5. Survive in Ground, Launch, and Space Environments; Operate in the Ground and Space Environments**
 - **6. Minimize Cost and Schedule Within the Constraints of the Mission Requirements**



Trim Mass System (2 of 5)



- **Derived Requirements**

- **1. Adjust the CG in the Radial Axis (in the X & Y Axis)**
- **1.1. Provide 4 Trim Masses in the X-Y Plane, 2 Trim Masses that Move in the X-Direction and 2 That Move in the Y-Direction, to Provide a Total CG Movement of +/- 10mm in Both the X & Y Axis**
 - **1.1.1. Each of These 4 Trim Masses Will Have a 6 kg Mass**
 - **1.1.2. Each of These 4 Trim Masses Will Have a Stroke of +/- 0.5 m**
 - **1.1.3. The 2 X-Direction Trim Masses Will Be Slaved to Move Together and the 2 Y-Direction Trim Masses Will Be Slaved to Move Together (Electrical)**
 - **1.1.4. Each Trim Mass Must Be Positioned to Within +/- 0.1 mm (TBR) of Desired**
 - **1.1.5. The Position of Each Trim Mass Must Be Known to +/- TBD mm**
 - **1.1.6. Provide Alignment Surface on Mechanism**
- **2. Adjust I_{xz} & I_{yz}**
- **2.1. Provide 2 Trim Masses Parallel to the Z Axis in order to Adjust 2 Products of Inertia (I_{xz} & I_{yz}) by +/- 1.1 kg*m²**
 - **2.1.1. Each of These 2 Trim Masses Will Have a 3.3 kg Mass**
 - **2.1.2. Each of These 2 Trim Masses Will Have a Stroke of +/- 0.333 m**
 - **2.1.3. Each Trim Mass Must Be Positioned to Within +/- 0.1 mm (TBR) of Desired**
 - **2.1.4. The Position of Each Trim Mass Must Be Known to +/- TBD mm**
 - **2.1.5. Provide Alignment Surface on Mechanism**



Trim Mass System (3 of 5)



- **Derived Requirements (Continued)**
 - **3. Provide Highly Reliable Operation Throughout Mission Life**
 - **3.1. On-Orbit Life of 5 Years**
 - **3.1.1 TBD Total Life Cycles Performed Once Every TBD Months**
 - **3.2. Use Redundant Electrical Circuits Where Practical (ie. Motor Windings)**
 - **3.3. Use High Force/Torque Margins**
 - **3.4. Use Appropriate Materials and Lubricates for Sliding and Separating Parts**
 - **3.4.1. Use Redundant Sliding Surface Where Practical**
 - **3.5. Perform Rigorous Qualification and Acceptance Testing, Environmental Testing IAW NCST-TP-FM001, *FAME Test Plan***
 - **4. Minimize Operational Impacts to the Mission**
 - **4.1. TBD Jitter Input Requirement and TBD Max Adjustment Speed Requirement**
 - **4.2. Command From Ground Based on Determination of On-Orbit Wobble (Man-in-the-Loop Control)**
 - **4.3. Minimize Impact and Cost on Ground Operations**
 - **4.3.1. Streamline and Automate Regular and Repetitious Ground Station Tasks**



Trim Mass System (4 of 5)



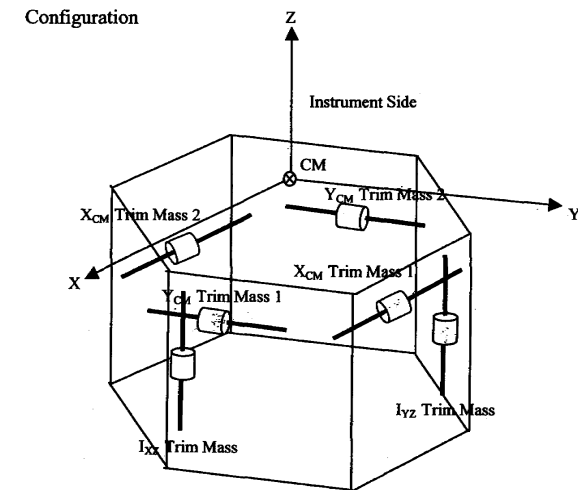
- **Derived Requirements (Continued)**
 - **5. Survive in Ground, Launch, and Space Environments; Operate in the Ground and Space Environments**
 - **5.1. Survive TBD Component Vibration Spec**
 - **5.2. Survive and Operate in -20 C to +40 C (TBR) Temperature Environment**
 - **5.3. Survive LV Pressure Decay Rate of 0.8 psi/sec Max and Operate in Hard Vacuum <10⁻⁵ torr**
 - **5.4. Survive and Operate in Lab Environment**
 - **5.4.1 Temperatures of 20 +/-5 C, 20-80% Humidity, and 1 Atmosphere**
 - **5.5 TBD Need to Provide a Launch Lock Mechanism to Support Masses During Launch**
 - **6. Minimize Cost and Schedule Within the Constraints of the Mission Requirements**
 - **6.1 Use Only 2 Motor Controllers to Drive all 6 Trim Mass Motors Such That One Can Drive Any 1 or 2 Trim Masses at a Time (Electrical Requirement)**
 - **6.2 Use the Same Motor for All Six Trim Mass Mechanisms**



Trim Mass System (5 of 5) - (Back-Up)



- **Design Approach**
 - 6 Motor Driven Trim Mass Mechanisms
 - Each Trim Mass Mechanism Consists of a Balance Mass Whose Position Is Adjusted by Stepper Motor Driven Leadscrew
 - Heritage Motor Mechanism Designs Available
 - Use Same Actuator for All 6 Trim Mass Leadscrews
 - Use Only 2 Motor Controllers and Switch Between Pairs of Motors to Drive
 - Allows Up to 2 Motors to Be Driven Simultaneously and Can Still Drive Each Separately
- **Trade Studies**
 - Specific Stepper Motor Actuator
 - Investigate Using LM Gravity Probe-B Trim Mass Mechanism Design
 - Adding Iz Trim Mass for Spin Rate Control
- **Long Lead Components**
 - Actuator – Stepper Motor 6-9 Months



Baseline Configuration and Orientations



Stepper Motor With Lead Screw



Trim Tab System (1 of 7)



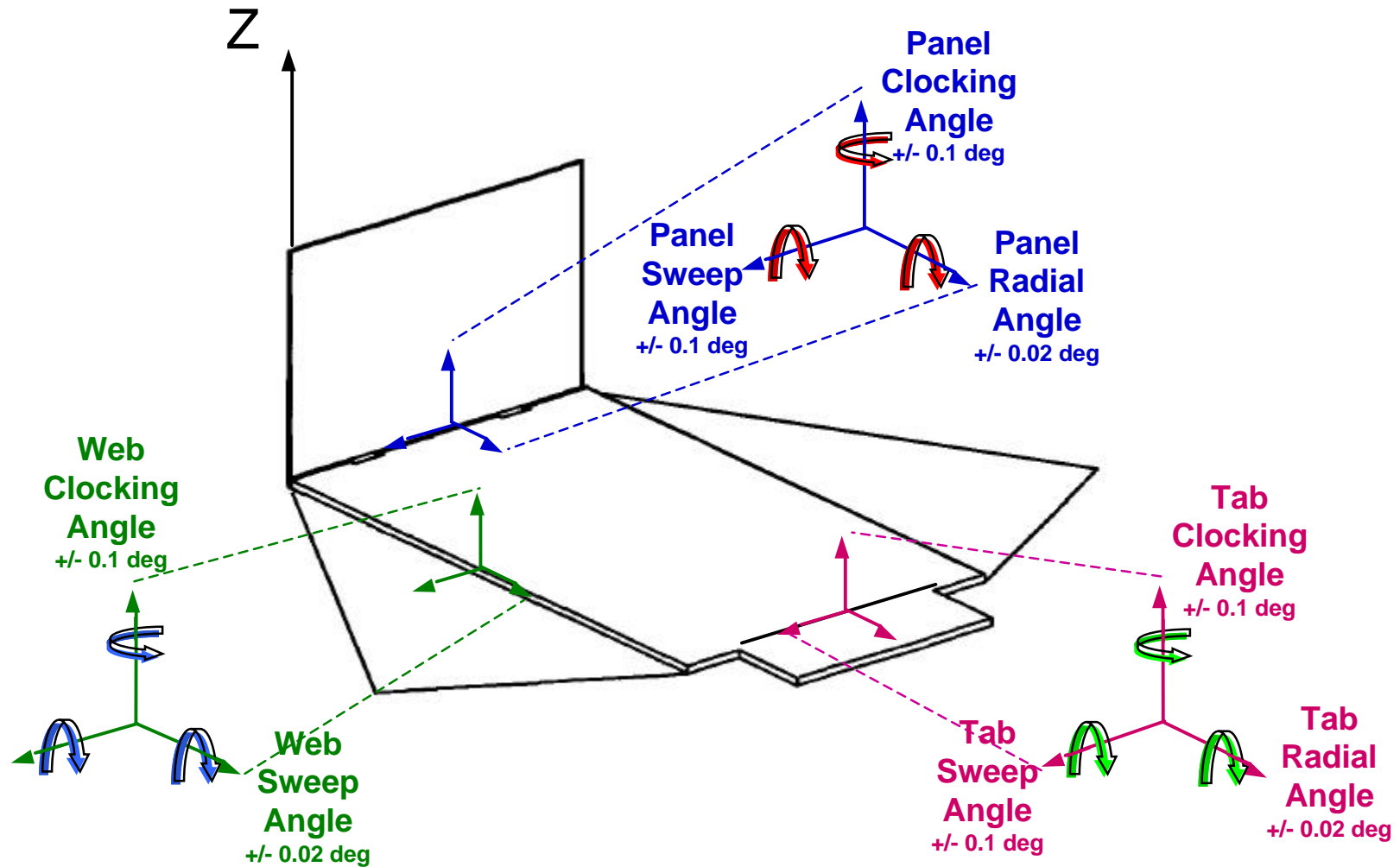
- **Top Level Requirements (MRD Rqmts Shown in Red)**
 - **0. Provide Radiation Trim Tabs in Order to Adjust the Solar Radiation Torque and Thereby Control the Precession Rate (Note: Adjustments Will Not Be Made During Stellar Mapping)**
 - **1. Provide TBD Solar Radiation Control Torque (ACS)**
 - **2. Provide Highly Reliable Operation Throughout Mission Life**
 - **3. Minimize Operational Impacts to the Mission**
 - **4. Survive in Ground, Launch, and Space Environments; Operate in the Ground and Space Environments**
 - **5. Minimize Cost and Schedule Within the Constraints of the Mission Requirements**



Trim Tab System (2 of 7)



Coordinate Frames





Trim Tab System (3 of 7)



- **Derived Requirements**
 - **1. Provide (TBD) Solar Radiation Control Torque (ACS)**
 - **1.1. Provide 6 Trim Tabs, One at the End of Each Solar Array Arm Assembly, Because of the Vehicle's Geometry and in Order to Maximize the Moment Arm of Each Trim Tab**
 - **1.2. Each Trim Tab Must Provide 1 DOF With at Least 90 deg. of Range (Perpendicular and Parallel to the Sun)**
 - **1.2.1. Each Trim Tab Must Have a Minimum Tab Sweep Angle Position of 0.02 deg (TBR)**
 - **1.3. Each Trim Tab Must Have the Following Geometry**
 - **1.3.1. Minimum Surface Area of 0.2 m² Each (TBR) Nominally 0.5m x 0.4m (TBR)**
 - **1.3.2. Flatness Better Than 5 mm Over 2 m (TBR)**
 - **1.4. Each Trim Tab Must Have the Following Optical Properties (Thermal Requirements)**



Trim Tab System (4 of 7)



- **Derived Requirements (Continued)**
 - **2. Provide Highly Reliable Operation Throughout Mission Life**
 - **2.1. On-Orbit Life of 5 years**
 - **2.1.1 TBD Total Life Cycles Performed Once Every TBD Months**
 - **2.2. Use Redundant Electrical Circuits Where Practical ie. Motor Windings**
 - **2.3. Use High Force/Torque Margins**
 - **2.4. Use Appropriate Materials and Lubricates for Sliding and Separating Parts**
 - **2.4.1. Use Redundant Sliding Surface Where Practical**
 - **2.5. Perform Rigorous Qualification and Acceptance Testing, Environmental Testing IAW NCST-TP-FM001, *FAME Test Plan***
 - **3. Minimize Operational Impacts to the Mission**
 - **3.1. TBD Jitter Input Requirement and TBD Max Adjustment Speed Requirement**
 - **3.2. Command From Ground Using Ground Based Attitude Determination of On-Orbit Wobble (Man-in-the-Loop Control)**
 - **3.3. Minimize Impact and Cost on Ground Operations**
 - **3.3.1. Streamline and Automate Regular and Repetitious Ground Station Tasks**
 - **3.4. The Minimum Adjustment Speed Is to Move All Trim Tabs by 10 Degrees (TBR) Within 2 Minutes (1/20 of Spin Rate) So As to “Instantaneous” Affect the Radiation Balance Within a Single Spin Revolution**



Trim Tab System (5 of 7)



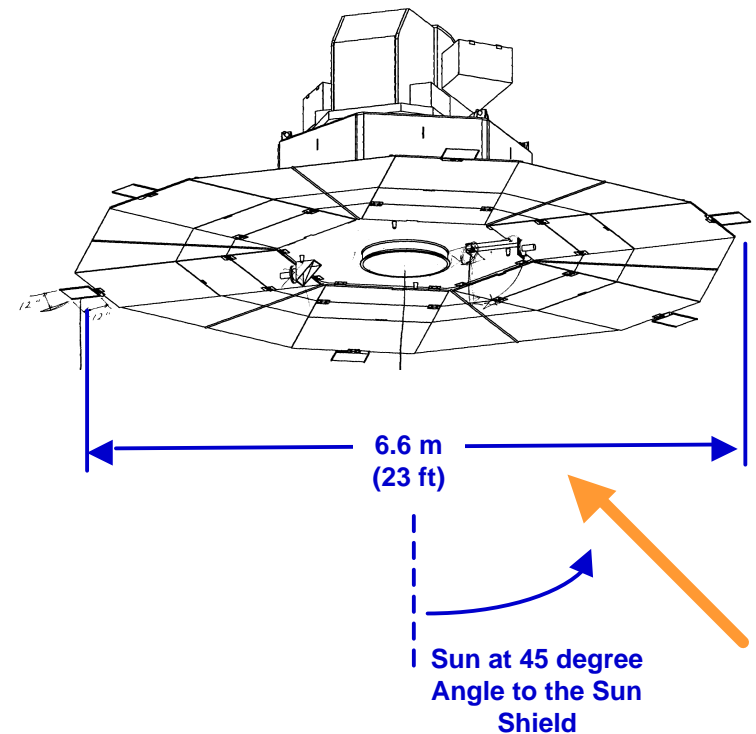
- **Derived Requirements (Continued)**
 - **4. Survive in Ground, Launch, and Space Environments; Operate in the Ground and Space Environments**
 - **4.1. Survive TBD Component Vibration Spec**
 - **4.2. Survive and Operate in -40 C to +80 C (TBR) Motor Temperature Environment**
 - **4.3. Survive LV Pressure Decay Rate of 0.8 psi/sec Max. and Operate In Hard Vacuum <10⁻⁵ torr**
 - **4.4. Survive and Operate in Lab Environment**
 - **4.4.1 Temperatures of 20 +/-5 C, 20-80% Humidity, and 1 Atmosphere**
 - **4.5 TBD Need to Trim Tab Retention Required During Launch**
 - **5. Minimize Cost and Schedule Within the Constraints of the Mission Requirements**
 - **5.1 Use Only 1 Fully Redundant Motor Controller to Drive All 6 Trim Mass Motors via Switches From One Tab to the Next (Electrical Requirement)**
 - **5.2 Use the Same Motor for All Six Trim Tabs Mechanisms**



Trim Tab System (6 of 7) - (Back-Up)



- **Design Approach**
 - 6 Trim Tabs Each Driven by Stepper Motors
 - Heritage Stepper Motor Designs Available
 - Use Same Actuator for All 6 Trim Tabs
 - Use Only 1 Fully Redundant Motor Controller and Switch Between Motors to Drive Each Tab
- **Trade Studies**
 - Whether to Use Motor to Move the Tabs or to Use Heaters and Create Thermal Thrusters (More of an ACS Use Trade Study Than Mechanisms)
 - Specific Stepper Motor Actuator
 - Spin Rate Control (Additional DOF)
- **Long Lead Components**
 - Actuator - Stepper Motor 6-9 Months
- **Issues**
 - Need Improved Requirements Definition
 - Especially If Trim Tabs Are Also to Perform Spin and Imbalance Adjustment





Trim Tab System (7 of 7) - (Back-Up)



- **Motor Driven Trim Tabs Verses Thermal Thrusters Trade Study**

	Motor Driven Trim Tabs	Thermal Thrusters
Design Simplicity	Fair (6 Motors & 1 Controller)	Excellent (Heaters and Relays)
Power Required	Excellent (None once Adjusted)	Poor (~270W x1.5 to 2 for Max. Equival. Torque, Can Reduce by Increasing Moment Arm)
Temperature Issues	Excellent (Minimal)	Poor (Need T~ 200 C) (Can Be Reduced by Increasing Tab Size)
Thermal Torque Issues	Unknown	Unknown
Weight	Good	Excellent
Testing Simplicity	Good	Excellent

- **Currently Motor Driven Trim Tabs Baselined Because of Current ACS Control Use**
 - Purely From a Mechanisms Point-of-View Prefer Thermal Thrusters if Heater Power Is Available